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DETERMINATION OF TRACK'S RADIUSES OF HEAVY CHARGED PARTICLES IN ALKALI HALIDE CRYSTALS

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A new approach to the estimation of track radius of heavy charged particle by the relationship investigation of simple and complex color centers in ionic crystals induced by ions and electrons stream from high-current accelerators is described. Track radius of krypton ion accelerated up to 117MeV in LiF crystal was estimated. Obtained value of the track corresponds to the known value estimated by other methods.

Keywords: heavy charged particle, ionic crystals, krypton ion, high-current accelerators.

Generally tracks sizes are determined from the investigation of nonlinear effects [1]. Individual heavy particle in material creates track with the high density of excitation in short period of time [2]. Density of excitation in the particle track can be found by the known values of incident particle energy, path length and track radius. For instance, for krypton ion with particle energy $E_ч$ = 117 MeV in LiF crystal, r_T = 12,5 nm (calculations were done by [1]), $R_T = 15\ \mu m$ and E_{cp}=1,6·10^{22} eV/cm^3. Traveling time of the particle in material that is time of track forming is about 10^{-12} s.

At low density of particle fluence in each track identical sets of formation processes and accumulation of the color are developing absolutely independent from each other. With fluence enhancement appears possibility of spatial track overlapping. For the case of irradiation by krypton ions track overlapping in space can be observed at fluence higher than 1· 10^{11} ions/cm^2. In the region of track overlapping the nature of imperfections will be different from observed in isolated track. It should be noted that relaxation of electron excitation in crystals and evolution of imperfections (transformation of color centers) develop for a long period of time, from 10^{-8} до 10^{5}s [3, 4]. Probability of track overlapping with the same degree of relaxation is negligibly small at any real density of irradiation. Therefore, at the irradiation of crystals by heavy charged particles in the case of absence of track overlapping relaxation processes in all tracks will be absolutely similar.

Process simulation, progressing in the single track of heavy high-energy particle can be carried out by using sources of pulsed radiation with high density of irradiation and short duration. Characteristics of such impulses must be close to characteristics in the particle track. The most suitable for simulation is pulsed electron stream, generated by high-current electron accelerator, with duration about 1ns. Although duration of electron stream impulse substantially is longer than time of particle energy releasing in the track, using of impulse of electron stream for stimulation is possible. The question is that created primary radiation defects remain changeless form until about (10 – 100) ns at 300K.

Thereby, simulation of processes progressing in the track of charged particle by using of material excitation by pulsed electron stream is possible using following approach: sets of processes of imperfection relaxation are similar at variation of absorbed energy by a factor of a hundred. Correction of received representations can be done on the basis of analysis (and extrapolation) of properties variation (characteristics) density research in a power range below the limiting.

The goal of this work is to search approaches to an estimation of spatial characteristics of particles tracks on the basis of the analysis of results obtained from investigation of color centers in alkali halide crystal at irradiation by heavy charged particles stream and impulses of high-current electron streams.

Theoretical justification

Let the sample is irradiated by a stream with the general fluence such that the probability of spatial track overlapping was small. This situation corresponds to a real situation at an irradiation on a cyclotron of type DC-60. Densities of ions flux on an accelerator exit have size of an order of 1010 $sm^{-2}s^{-1}$. At such densities of the stream it can be considered that in each separate track all events, activated by incident particle are similar and independent of processes occurring in other tracks.

Let us present a track as the cylinder with radius r_T, containing F, F_2 – the centers and complementary to them the hole color centers. Then at low density of tracks the part of probing radiation at measurement of optical density – D (transmission coefficient-τ) of the sample passes through created tracks (D_T , τ_T), another part passes through the area of a crystal which is not containing tracks (D_0 , τ_0). Let us establish connection between integrated transmission coefficient of the sample τ, irradiated by heavy particles, with transmission coefficient in the area of tracks τ_T and out of track τ_0. Assuming that $\tau_T = const$ and $\tau_0 = const = 1$, and the area of a single track $\pi r_T^2 = const$ we will receive:

$$\tau = 1 - \pi r_T^2 \cdot N(1 - \tau_T), \tag{1}$$

where N is a number of tracks on surface unit.

According to (1) integrated transmission coefficient of the sample is connected with transmission coefficient in the track and track radius. Hence, according to the experimentally measured value of integrated transmission coefficient, it is possible to find track radius if the transmission coefficient of the track with the color centers is known.

To create the same set of defects (by relation and concentration) which is created in a track is possible using powerful impulse of electron stream.

Let concentration of F centers induced by an electronic bunch is equal n_{Fe}. If $n_{Fe} = n_{FT}$ (n_{FT} - concentration of F centers in the particle track), then

$$\chi_T(F) = \chi_e(F),$$

where $\chi_T(F), \chi_e(F)$ – absorption indexes in maxima of F – bands in the track and in the crystal irradiated with electrons. Then transmission coefficient τ_T is connected with optical density in the particle track (or in irradiated with a impulse of electron stream in the crystal) by relation:

$$\tau_T = e^{-D_T} = e^{-\chi_T R_T} = e^{-\frac{D_e}{R_e} R_T}, \tag{2}$$

where D_T , R_T and D_e, R_e optical density and ion and electron path length in a crystal respectively. Substituting (2) into (1) we will obtain expression for determination of track radius:

$$r_T^2 = \frac{(1-\tau)}{\pi N}\left(1 - e^{-\frac{D_e}{R_e} R_T}\right)^{-1} \tag{3}$$

In the expression (3) D_e is optical density of the sample with induced F centers by electrons impulse, which concentration are equal to the concentration of F centers in the particle track.

D_e value can be found by using following statements.

1. It is known that at homogeneous (uniform by volume) irradiation of a crystal, relation between concentrations of F and F_2 centers under constant conditions of an irradiation and measurement is constant:

$$k = n(F_2)/n^2(F) = \text{const}$$

It can be concluded that

$$\frac{D_e(F_2)}{D_e^2(F)} = k^* \tag{4}$$

is also constant value, which can be found directly from results of experimental researches.

2. At the equality of F centers concentration in the particle track and in the sample irradiated with impulses of electron stream, it should take place equality of F_2centers concentration as well. Then it should be true following equality:

$$\frac{D_e(F)}{D_e(F_2)} = \frac{D_T(F)}{D_T(F_2)} = \frac{D(F)}{D(F_2)} = k_1^*, \tag{5}$$

where *D(F)*, *D(F₂)* – optical density in maxima of F, F_2 – bands in the crystal irradiated with ions. According to (5) coefficient k_1^* is defined directly from absorption spectrum of the crystals irradiated with a stream of heavy particles.

The joint decision of the equations (4) and (5) allows finding that value of optical density in maximum F – absorption bands in $D_e(F)$ crystal irradiated with electron stream, to which corresponds F centers concentration that equals to F centers concentration in a particle track:

$$D_e(F) = 1 \big/ k^* k_1^* \tag{6}$$

Having substituted value (6) in (3), we will find track radius.

Experimental results

For an estimation of possibility and accuracy of tracks radiuses determination of heavy charged particles following experimental researches have been done. For researches LiF monocrystals, which has been grown up in State Optical Institute of Vavilov were used. Plates of monocrystals were obtained by pricking out perpendicularly to <100> direction of a crystal.

For modeling of processes in tracks of heavy particles we used small-sized high-current accelerator RADAN -220. The accelerator provides generation of electron stream impulses with average energy of accelerated electrons 150 KeV, duration of impulse 2 ns, beam current in an impulse to 1000A. The irradiation was executed on air at 300K. The electron stream was deduced through an Al-foil. Depth of penetration of electrons into the crystal R_e has been measured by visible depth of colouring of crystal cleavage and it was equal to 0.15 mm. To guide by single impulse of electron stream the same concentration of defects as in particle track is impossible: the sample collapses at excitation density almost on two orders below the necessary. Therefore, the estimation of F centers concentration in the track can be made only by extrapolation of research results of induced F centers concentration dependence on a dose of the irradiation with impulses of electron stream.

Absorption spectra induced by the irradiation electron stream of LiF crystals were measured depending on an irradiation dose (number of electron stream impulses). Spectra had a characteristic appearance for these crystals with well expressed F - and F_2 – bands. Experimentally measured values of optical density in maxima F - and F_2 – bands are presented in table 1.

Table 1 Experimentally measured values of optical density in maxima F - and F_2 – bands in LiF crystals irradiated by electrons at accelerator RADAN -220 with i^{th} number of impulses.

i-number of impulses	$D_e(F)$	$D_e(F_2)$
10	1,514	0,128
20	2,408	0,139
40	3,324	0,128
60	3,817	0,186
70	4,423	0,199
80	4,605	0,186

On the basis of processing results of experimental data which are presented in the table 2, it has been found that k^* is equal to 0.015.

Crystals were irradiated by heavy charged particles at cyclotron DC-60 of the Eurasian National University of L.N.Gumilyov. As the heavy charged particles krypton ions with energy 117 MeV have been chosen. The current in an ionic beam was 23 nA and constant. The irradiation was executed on air at room temperature. Absorption spectra of irradiated LiF crystals had a characteristic appearance for these crystals with well expressed F - and F_2 – bands. Depth of penetration of krypton ions into the crystal R_T has been measured by visible depth of colouring of crystal cleavage and it was equal to 15 microns. Results of measurements of optical density in maxima F - and F_2 – the bands, necessary for k_1^* coefficient determination by (5) are represented in the table 2. In the same table results of calculations of tracks radius and values $k_1^*, D_e(F), \tau, r_T$ from (3,5) for various fluences are presented in the table 3.

Table 2 Experimentally measured values of optical density in maxima F - and F_2 – bands in LiF crystals irradiated by various fluences Φ of 84Kr ions with energy 117 MeV.

N – ions fluence, ion/cm^2	$D(F)$	$D(F_2)$	k_1^*	$D_e(F)$	τ	r_T (nm)
6•10^{10}	0,55	0,13	4,2	15,8	0,58	13
1.2•10^{11}	0.81	0.14	6	11,1	0,45	9,5
1.7•10^{11}	1,19	0,32	3,6	18,5	0,31	10
2,5•10^{11}	1,63	0,43	3,8	17,5	0,2	9

Some differences and disorder of the received values can be explained by insufficient stability of work of accelerators which are in an adjustment stage.

Conclusion

The track according to the stated approach represents itself the cylinder with radius r_T, the average size of optical transmission τ_T along which corresponds to criteria of (4 and 5). Value of τ_T is defined by spatial density of the induced centers and a parity of the simple and complex color centers. Therefore, value of τ_T reflects excitation density in the area of energy transmission from particle to a crystal. It is obvious that at different methods of radius estimation, its value should vary a little, so far as in each method the criteria, approach in definition of radiuses values are entered differently. Values of tracks radiuses presented in the table 3 are close to the values found in [1] method. The offered method allows making estimations of tracks radiuses of various particles with various energies using simple measurements of the induced optical absorption.

References:

Schwartz K., A.E. Volkov, M.V. Sorokin, C. Trautman, K.-J. Voss, R. Neumann, and M. Lang. Effect of electronic energy loss and irradiation temperature on color center creation in LiF and NaCl crystals irradiated with heavy ions // Phys.Rev.B 78 024120, 2008.

Lisitsyn V.M. Radiation physics of solid.– Tomsk: Tomsk Polytechnic University Press, 2008. – 170 p.

Lisitsyn V., Yakovlev V.I.,Korepanov V.I. Destruction kinetics .of M centers in MgF_2 crystals after impulse electron irradiation$_2$ // FTT.-1978.-**Vol.20**, N3.- 731-733 p.

Lisitsyna L.A.. Electron color centers creation behavior in LiF crystals under impulse irradiation // Izv. Vuzov Fizika.- 1996. -№11. -p.p.57-75.